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MINING METHODS AND COSTS AT THE VANADIUM MINE OF THE UNITED STATES VANADIUM CORPORATION, RIFLE, COLO.

BY

BLAIR BURWELL

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MINING METHODS AND COSTS AT THE VANADIUM MINE OF THE UNITED STATES VANADIUM CORPORATION, RIFLE, COLO.[1]

By Blair Burwell[2]

INTRODUCTION

This paper describing the method of mining a deposit of vanadium ore near Rifle, Colo., is one of a series of similar papers on metal-mining methods and costs being issued by the United States Bureau of Mines. This vanadium deposit probably is the largest yet found in North America. It is situated 12 miles northeast of Rifle, Colo. (see fig. 1), on the southern flank of the White River plateau, and is at an altitude of 6,500 feet. Between 150 and 200 tons of ore are mined daily and trucked to the mill at Rifle. The product of the mill is fused vanadium oxide, which is shipped to the company's plants at Columbiana, Ohio, and Niagara Falls, N. Y., for the electric manufacture of ferrovanadium.

HISTORY

The deposit was discovered about 1909 by men prospecting for carnotite. Its outcrop on the bold cliff of Rifle Canon had been known to stockmen for many years.

A local company was formed in 1921, and after a preliminary period of development and financing, a salt-roast treatment plant with a capacity of 50 tons per day was built at Rifle. In 1926 the property was purchased by the Union Carbide & Carbon Corporation. After this purchase a new deposit was discovered on one of the properties, and the capacity increased to 50,000 tons of ore yearly. Since that time the property has operated steadily at capacity.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6662."

[2] One of the consulting engineers, U. S. Bureau of Mines, and superintendent of the vanadium mine of the U. S. Vanadium Corporation.

GEOLOGY

The deposits belong to the general classification of disseminated deposits in sandstone, and occur as interbedded lenses in the McElmo sandstones of Jurassic or Cretaceous age. Their origin is a matter of considerable speculation, as is the origin of the similar and often associated sandstone deposits of carnotite, gold, silver, and copper. A study of the structural features of the Rifle deposit in relation to the problem of origin has, however, resulted in the finding of ore with a minimum of prospecting.

The immediate formations make up a lenticular assembly of sandstones, impure limestones, and clays which fill a structural basin or depression in the Permian Red Bed surface. Overlapping sandstones were built out into the depression from the northwest. The ore sands, or vanadium-bearing sandstones, occur as fairly uniform, cross-bedded lenses, covering areas from 300 to 700 feet long and from 200 to 600 feet wide, with a thickness varying from a few inches to 30 feet (fig. 2). The trend of the deposits is from the northeast to the southwest. The southwest limits are marked by the structural lensing out of the sands on the Red Bed basement.

Several northeast channels have been located. One of these channels which has been followed for 600 feet, contains an orebody 25 to 50 feet wide and 5 to 20 feet thick (fig. 3). Associated with the vanadium bodies are similar lenses in which finely divided carbonaceous matter is bedded in the sandstones.

The ore is a mixture of oxides of vanadium to which no definite mineral name can be given. Uranium is present in a small amount, as well as occasional silver minerals.

CHARACTERISTICS OF THE ORE AND OREBODIES

The ore is tough, blocky, and highly abrasive. The dip of the orebodies ranges from 25° near the outcrop to 15° in the lower portions. The overburden averages 300 feet in thickness. The ore-bearing sandstone itself is from 50 to 75 feet thick, and generally forms a strong roof over the mine workings, although near the edges of the deposit cross-bedding sometimes causes loose slabs. Although much of the ore can be recovered without extensive roof support, yet the obtaining of a high percentage of ore recovery makes roof support necessary. The strength of the roof is in one respect an unfavorable factor, in that progressive roof caving can not be done, and provision must be made for heavy squeezes over large areas in retreating.

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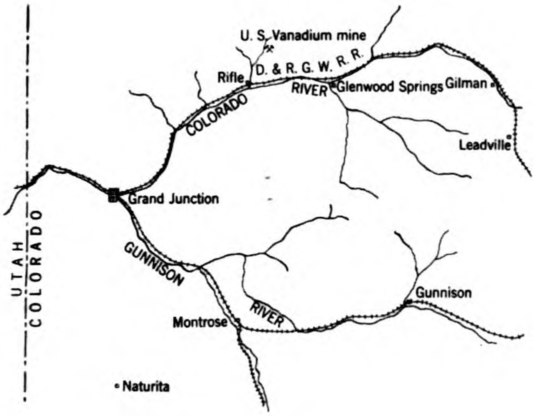

Figure 1.—Location of Vanadium mine

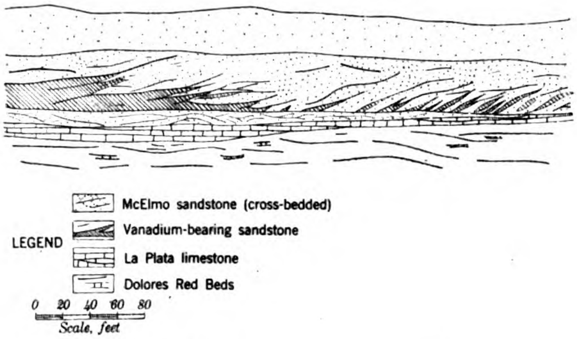

Figure 2.—East-west cross section showing ore bedding

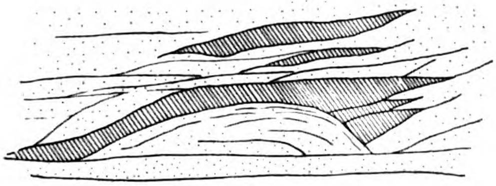

Figure 3.—Cross section of channel orebody

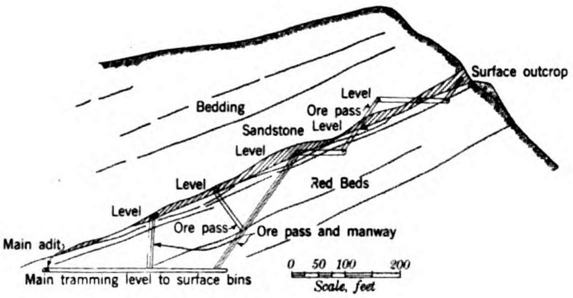

Figure 4.—Section of mine workings showing method of development

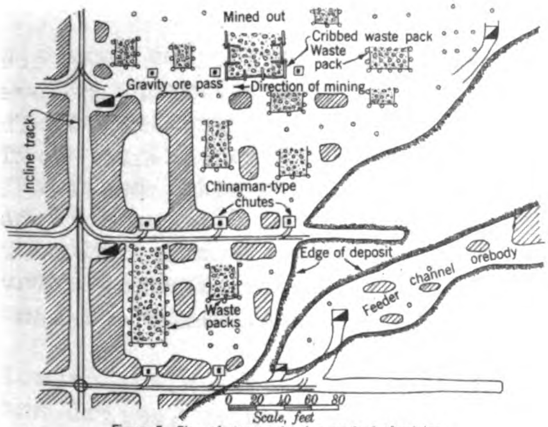

Figure 5.—Plan of stopes, showing method of mining and of supporting back

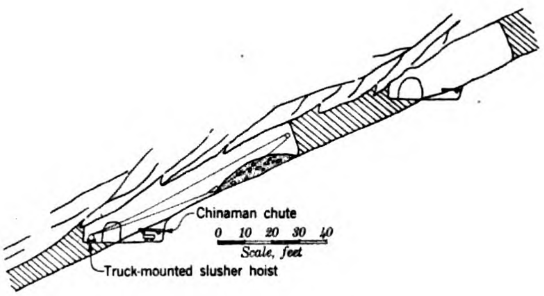

Figure 6.—Section through a stope, showing use of slusher

PROSPECTING AND EXPLORATION

The deposits outcrop on the eroded flank of an anticline. The early exploration was by drifts driven in from surface exposures, following the strike of the ore. Later diamond drilling with vertical holes from the surface was used to prospect the areas back of the outcrops. Although drilling discovered the main orebodies, extensions and channels are explored by drifts and raises in the ore, or in directions suggested by the structure.

SAMPLING AND ESTIMATES OF TONNAGE

Channel samples are cut by moil from foot to hanging at intervals of 10 to 20 feet along the openings as they progress. After plotting and recording the thickness and grade on sample maps showing the plan of the orebodies on a scale of 40 feet to the inch, the sampling channels are painted in the mine in a range of four colors, using a water paint, which shows at a glance the grade between 1 and 5 per cent vanadium oxide. This visible marking is an aid to selective mining and the maintaining of a uniform mine grade. Tonnage is estimated on the basis of 12.5 cubic feet per ton of ore in place.

Mill heads are controlled by breaking ore according to underground sampling. Dilution with waste rock varies with the thickness of the ore, being greater in thin and tight ore where heavy powder charges cause overbreaking. A dilution factor dependent on the ore thickness is used in making the estimate.

DEVELOPMENT AND MINING

The main entry is by a tunnel driven on the strike of an orebody which was first developed at the surface. Diamond drilling later disclosed an orebody to the northeast and on a higher level than this main tunnel, which enabled the mine development to be planned in advance.

A crosscut was driven from the main entry 475 feet into the Red Beds formation and under the approximate center of the upper orebodies. From that point a 3-compartment ore pass, manway, and skipway was driven 280 feet at a 55° slope to an intersection with the ore beds (see fig. 4). From the crosscut and inclined raise other raises were driven to intersect the orebodies at intervals of about 120 feet on the dip, this interval being selected as the most economical slushing distance from level to level. The system of gravity raises and crosscuts in the footwall, designed to preserve haulage ways in the process of retreating, is continued in following the ore to the surface.

Below the main level, extensions of the orebodies are followed with inclines and drifts, using small electric hoists for raising ore to the main tramming level.

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The main ore pass and manway is 6 by 18 feet, with a timbered compartment in the center, separated by 6 inches of planking and 45-pound steel rails from the ore passes on the sides. Raise sets are of 10 by 10 inch timbers. Frequent inspection holes at the manway landings give access to ore hang-ups in the chutes.

Inclined stairs and tracks on the dip of the deposit extend from level to level and serve for the distribution of materials and as manways. These inclines are in portions of the orebodies which are easy to keep open.

Adits and crosscuts generally require no timber support, with the exception of an occasional drift set near a fault or fracture zone. They are driven 6 by 7 feet in the clear, using a 15-hole V cut, or a 16-hole burn-out cut, the latter being used with increasing favor where blasting near slushers or other equipment. Drifts in ore are 6 by 7 feet for a single machine face, or if followed by the air-operated shovel, 8 by 12 feet, using two machines and a center V cut.

Mucking of drifts and crosscuts is mainly by hand, except that mucking in drifts in very thick ore is done with the air shovel, and that slushers are used in starting drifts from raises.

Raises are driven 5 by 10 feet where a manway and ore pass are combined, or 5 by 7 feet as an ore pass. The burn-out cut generally is used in raises where timbers and bulkheads are close to the face. Raises driven in ore from level to level are 12 by 6 feet; the ore is pulled to the bottom by slushers.

For drifting, Gardner-Denver 107, Ingersoll-Rand L-74, and Chicago Pneumatic No. 5 drifters are used. These are equipped with anvil-block chucks and use 7/8-inch hexagonal steel without lugs, the same steel being used for both stopers and drifters. Drifters are equipped with long shells and feed screws so that a 32-inch change can be made. Only two pieces of steel are used in an average set, the first being 40 inches long with a bit $1\frac{3}{4}$ inches in diameter, and the second 72 inches long with a bit 1-5/8 inches in diameter. Formerly lugged steel and steel pullers were considered necessary, but the use of lugless steel with the longer chuck alignment has reduced the amount of stuck steel to a minimum, and the wear on the steel and chucks has been decreased.

Cross bits with a straight 14° taper have proved more satisfactory than the double taper for use in this mine. About 35 per cent more footage per set of steel is obtained with the 14° taper. Stellite has been used with some success on the reaming edges of bits, increasing the duty per set about three times. Water under drilling pressure is piped to all faces, and all drills are run wet.

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The explosive used is Du Pont special dynamite of density "G," having a stick count of 165 per box. This low-density explosive has proved more economical than the 35 per cent straight dynamite and gives a greater fragmentation in the primary blasting due to the longer powder string per pound of explosive. Fumes cause no trouble because of the well-ventilated condition of the mine.

Rounds are fired in drifts, crosscuts, and short raises by fuse and caps. In long raises electric blasting has been used.

Stoping

Underground stoping is classed at this mine as thin-ore mining, thick-ore mining, and average-ore mining. Thin-ore mining involves the stripping and sorting of ore extensions as little as 10 inches in thickness. The greater part of such stoping is done by slushers using a special low type of scraper 12 inches high and 5 feet long. In some cases breast stoping is practiced.

Thick ore is mined mainly by slushers, but a Butler-Nordberg air-operated shovel is used to some extent for breast stoping in high ore. Ore of average thickness is mined by slushers, using a Chinaman-type chute for loading into cars at the level.

A considerable amount of hand mucking is done, mainly near chutes and where sorting of ore in the stopes is necessary. This hand mucking generally is limited to starting stopes, or where the control of grade requires a temporary shift from larger-scale mechanical production of lower-grade ore to the selective mining of higher-grade ore held in reserve for this purpose.

Stoping follows a room-and-pillar system somewhat as in coal mining. Rooms and pillars are each 25 feet wide. Short crosscuts on 50-foot centers are run into the footwall from the levels in the ore, which are at 120-foot intervals on the dip; open chutes of chinaman type are constructed at the ends of the crosscuts. A panel of ore 25 feet wide and extending to the level above is then mined; the ore is removed by a slusher, operated by a double-drum, air-operated hoist mounted on a truck (see figs. 5 and 6). The stope is extended by driving a 12-foot face, using a center V cut, followed by side-slabbing rounds to the full width of 25 feet. After the first panels are mined from level to level the pillars are attacked, either from new chutes or by scraping on an angle from the old chutes. Sometimes the maintenance of grade makes sublevels necessary, the result being to reduce the long panels to a number of small pillars.

Roof support generally is not needed in mining the initial stopes, with the exception of occasional stulls to serve as a warning and to hold small roof slabs. Where waste is available from development above, or from surface bench mining, stopes are filled with waste lagged off from the pillars by log cribs in high ore, or by stulls and lagging or wire in average ore. The waste is brought into the stopes in cars, or by using slushers. As indicated in Figure 5, large waste packs are spaced in preparation for a heavy squeeze which may occur in the recovery of the last pillars, from 10 to 20 per cent of the area being supported in this way. On the levels, waste packs are spaced according to the ground. These are 20 feet by 15 feet, made with stulls and heavy woven wire, and are filled with waste from sorting or development. Figure 7 shows the several types of roof support used.

The pillars are finally blasted and the remainder of the ore slushed out. Stulls are used in weak places in addition to the waste packs previously placed.

Drilling is done with self-rotated wet stopers, the models used being the Gardner-Denver 77-H, and Ingersoll-Rand R-51 and S-49. The present tendency is to use the lighter type of stopers. Self-rotated stopers, using an adjustable stop board and drilling holes from 15° to vertical have proved more economical than using a column and a mounted machine for the reason that more holes can be drilled per shift with less interference with slushing operations. The higher upkeep cost due to chuck wear is overbalanced by the greater tonnage broken. The same steel is used as in drifting, but with 16-inch length changes, starting with a 24-inch steel and a 2-inch bit, and with an 1/8-inch reduction to the 7-foot 4-inch finisher with 1½-inch bit. Blockholing is done with Ingersoll-Rand BAR-33 jackhammers, using collared steel.

In slusher mining, two helpers and a machineman make up a slusher crew; these men place the eyebolts for cables, blockhole coarse ore, and load and tram cars to the level grizzly. In some stopes sorting is done and the waste used for packs. In high ore 500 tons or more is broken in advance of slushing, but in average ore the ore is moved as broken. The tonnage put into the transfer raise on the level ranges from 30 to 75 tons per slusher crew per shift.

The cable used in slushing is 3/8-inch, 6 by 19 plowsteel with wire center. The sheaves are a shrouded, roller-bearing type built at the machine shop (fig. 8). Chain swung from eyebolts in the sides of the stope is used to support the special sheaves. Double sheaves of similar design are used in angle pulls from the stope.

Waste handled in the mine is about 25 per cent of the ore tonnage.

Surface mining consists of an open-cut where the ore outcrops. Here an air-operated shovel was used, first stripping the waste, which was used for fill in stopes below, then mining the ore.

UNDERGROUND HAULAGE

The ore, as stated before, has a tendency to break into blocks. It packs and hangs up in the chutes wherever tamping action from the dumping of cars occurs. Ore passes are therefore large and provided with inspection holes; chute gates are 36 inches wide. On the main ore passes air-operated finger gates are used. On secondary chutes steel arc gates are standard. Stop-board chutes are not used.

Grizzlies over transfer raises on the several levels have 10-inch openings and are made from 80-pound rails with cast-iron dividers. The main ore pass has a capacity of 600 tons and the combined underground storage capacity is 1,000 tons.

Tramming is by hand; a special low-type, roller-bearing car of 1-ton capacity is used, which is increased by side boards to 1¼ tons for slusher service, and to 1¾ tons for shovel or main tram service. Grades are 0.75 per cent in favor of the load; cars are equipped with foot brakes and removable seats.

The length of the tram from stope chutes to level grizzlies ranges from 50 to 800 feet. The tramming distance on the main level from the main ore pass to the portal is 1,500 feet. This loading and hand-tramming operation has been raised to a maximum efficiency by air-operated chute gates, car brakes, and attention to the track. This is believed to be the maximum distance that hand tramming can be used more economically than mechanical haulage at this mine. The tonnage trammed per day from the main ore pass chute is 100 to 150 tons, and the cost is slightly under 9 cents per ton. This ore, with the ore from other closer chutes, is dumped over an inclined grizzly at the mine portal, where an average of 4 per cent is discarded as waste.

At the mine portal an inclined tram lowers the ore into loading bins at the road, a distance of 300 feet below. The upper bin has a capacity of 75 tons, and the loading bin at the road of 300 tons. Air gates, 1½-ton self-dumping skips, and a gravity-operated lowering drum equipped with Johns Manville brake blocks have made a satisfactory installation with a capacity of 250 tons per 8 hours. White trucks with a 6½-ton load are used to move the ore to the mill, a distance of 12 miles on a down grade.

The blacksmith shop (fig. 9) and mine buildings are in the valley at the foot of the tram. A jig-back cable with an electric hoist handles steel, cars, timbers, and materials from the track at the blacksmith shop to the main level portal.

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WAGES AND BONUS SYSTEM

At present the policy of the Company is to give employment to the largest possible number of men and no bonus is paid. In the past, however, contracts or bonus methods of several kinds were in effect.

For mining, a crew of two would be given a contract, where otherwise three men would be used on company operation, on the basis that 50 per cent of the saving in labor cost would be paid as a bonus. Bonus calculations were based on the labor cost per ton produced from the stopes, automatic car-counting devices on levels being used as a check. In drifting, the same method was used, based on the saving per foot of advance. Company costs on a prior 6-month period were used as a base rate. The mining of thin ore was done on the basis of a ton of clean ore delivered at the chutes.

Considerable adjustment was necessary in obtaining the correct standard or normal duty per man, but the system was successful in overcoming the inertia of labor toward a maximum day's work, and in reducing costs. The experience taught, however, that care must be taken to prevent the over head cost of administering such a system from exceeding the direct savings.

VENTILATION AND SAFETY

A small blower and 2,000 feet of flexible canvas tubing were used in the preliminary development of the mine, but after connections were made to the surface the natural ventilation was sufficient; in fact, air doors were necessary to check the drafts in winter. Fire hazards are small because of the great number of passageways and the relatively small amount of timber, but water is piped to the main raises, and no accumulation of scrap timber is allowed.

Several first-aid teams are organized, and compete with other State teams, so that nearly all the men in the mine have had first-aid training. The first-aid team looks after the maintaining of underground first-aid supplies, stretchers, and other equipment. Hard-toed shoes and "hard-boiled" hats are supplied, but their use is not compulsory. The mine has never had a lost-time accident from a fall of ground.

Table 1.- Summary of costs per ton trammed, in units of labor, power, and supplies, July, August, and September, 1931 (14,623 tons of ore mined and trammed)

	Development	Stoping	Total
A. Labor:			
Breaking (drilling and blasting)..man-hours per ton	0.03	0.30	0.33
Timbering and filling .... do.	--	.24	.24
Shoveling .... do.	.10	.90	1.00
Haulage and hoisting .... do.	.02	.26	.28
Supervision .... do.	--	.01	.01
General .... do.	--	.01	.01
Total labor underground .... do.	.15	1.72	1.87
Total ore trammed per 8-hour man-shift .... tons	53.33	4.65	4.28
Labor, percentage of total cost	--	--	60.00
B. Power and supplies:			
Explosives .... lb. per ton	.11	1.05	1.15
Total power .... hp. hours	--	1.00	1.00

Table 2.- Summary of underground costs per ton of ore trammed, July, August, and September, 1931 (14,623 tons ore trammed)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Development	$0.10	$0.01	$0.01	$0.02	$0.04	-	$0.02	$0.20
Stoping	.74	.05	.09	.13	.20	$0.04	.10	1.35
Transportation (underground)..	.24	-	-	-	-	-	-	.24
General underground expense ..	.02	.05	-	-	-	.02	-	.09
Surface expense (directly applicable to underground operation)	.08	-	-	-	-	-	-	.08
Total	1.18	0.11	0.10	0.15	0.24	0.06	0.12	1.96

(1) Labor
(2) Supervision
(3) Compressed air, drills, and steel
(4) Power
(5) Explosives
(6) Timber
(7) Other supplies
(8) Total

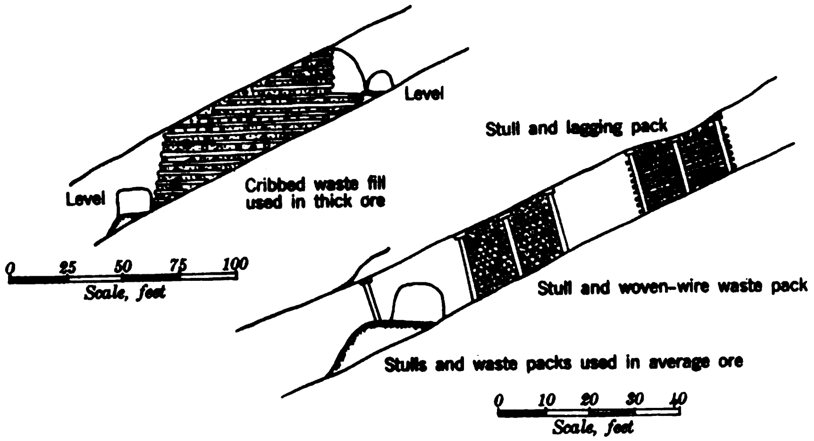
Level
Level
Cribbed waste fill used in thick ore
0 25 50 75 100
Scale, feet
Stull and lagging pack
Stull and woven-wire waste pack
Stulls and waste packs used in average ore
0 10 20 30 40
Scale, feet

Figure 7.—Types of roof support used in stopes

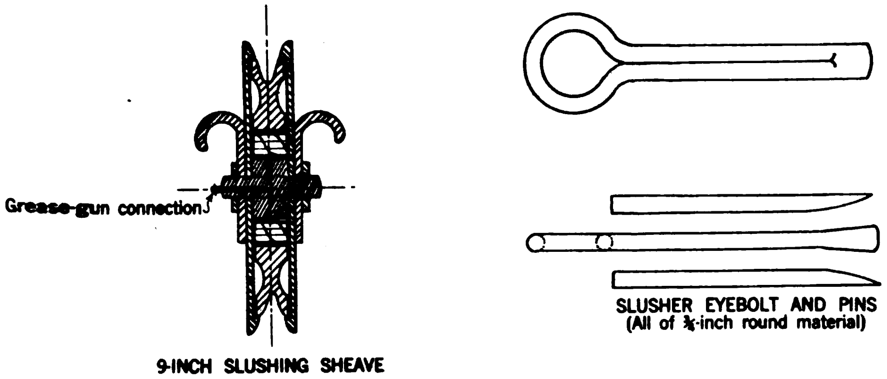

Figure 8.—Slusher sheave, eyebolt, and eyebolt pins

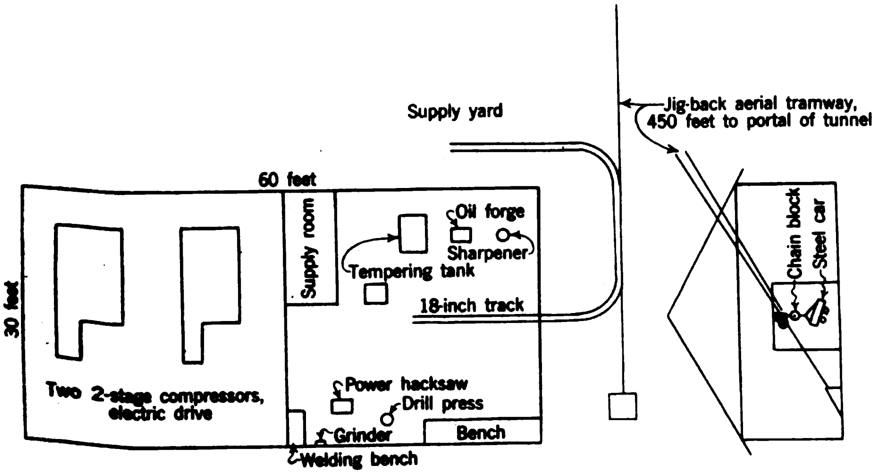

Figure 9.—Blacksmith shop and compressor plant